The ILC Project
Physics Studies and Detector R&D

Marco Battaglia
UC Berkeley and LBNL

LBNL Director's Review
November 8, 2005

The International e^+e^- Linear Collider

ILC highest priority for future major facility in HEP needed to extend and complement LHC discoveries with accuracy which is crucial to understand nature of New Physics, test fundamental properties at high energy scale and establish their relation to Cosmology;

Technology decision promotes ILC towards next stage in Accelerator design definition, R&D and cost optimisation: highly successful Snowmass workshop in August 2005;

Matching program of Physics studies and Detector R&D needed develop new accurate and cost effective detector techniques from proof of concepts to a state of engineering readiness to be adopted in ILC experiments.

ILC Project Personnel

2.0 Staff FTEs*

+1.25 PostDoc

+ 2.0 GSR FTEs

+ 6 UnderGrads

with UCB URAP

* **Marco Battaglia (PI) (UCB Faculty and LBNL Faculty Staff)**
  Detector R&D, Simulation and Physics Analysis, LDC Study coordination
* **David Brown and Michael Ronan (LBNL Senior Staff)**
  Reconstruction software
* **Yury Kolomensky (UCB Faculty and LNBL Faculty Staff)**
  Machine Instrumentation R&D
* **Gerry Abrams and John Kadyk (LBNL Retired Staff)**
  Detector R&D
* **Devis Contarato and David Lopes Pegna (LBNL Postdocs)**
  Detector R&D
* **Lauren Tompkins and Benjamin Hooberman (UCB GSR)**
  Detector R&D
* **Toyoko Orimoto (UCB GSR)**
  Machine Instrumentation R&D
  Tae Sung Kim and Marat Freytsis (UCB Guests)
  Detector R&D
* **Tankut Can, Bill Chickering, Khushnuma Koita, Linda Leung (URAP UnderGrads)**
  Detector R&D and Physics Analyses
* **Lauren Alsberg, Oleg Khainovski (URAP UnderGrads)**
  Machine Instrumentation R&D

* FTEs reflect effort not cost

ILC Project: Recent Accomplishments

Linear Collider activities carried out since several years in Physics division

- **LCRD** on Beam Instrumentation started in 2003;
- TPC R&D contributions within Intl. Collaborations;
- **LDRD** program on Monolithic Si Pixel Detectors approved
- in August 04 and renewed for FY06;
- ILC Project created in October 04:

Main Activities in FY05:

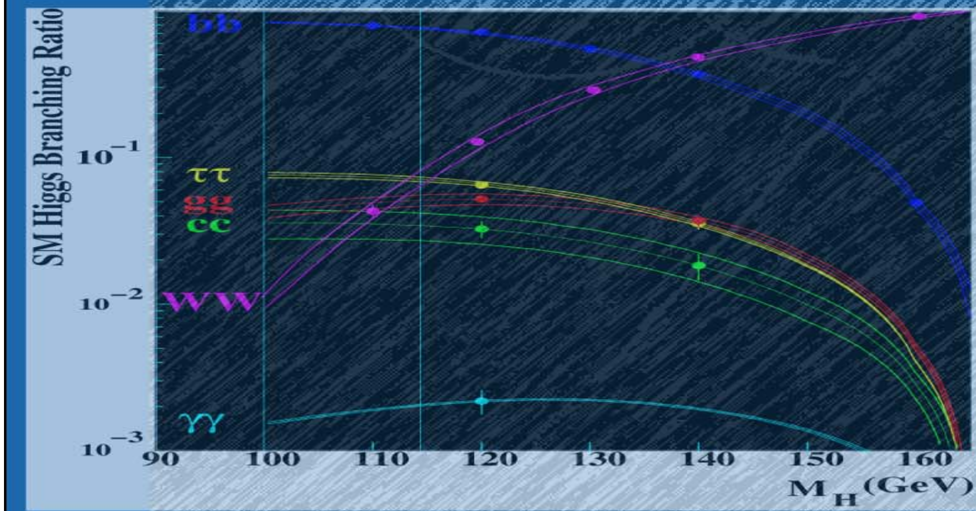
- ***Study of Cosmology and ILC Physics Connections***
- ***Definition of Physics Benchmarks for Detector Concept and Optimisation***
- ***Start of Large Detector Concept Study and Gaseous Detector Design***
- ***Setup of ILC Laboratory for Advanced Detector R&D***
- ***R&D on Monolithic Pixel Sensors and VLSI TPC Readout***
- ***Beam Test of BPM Instrumentation***

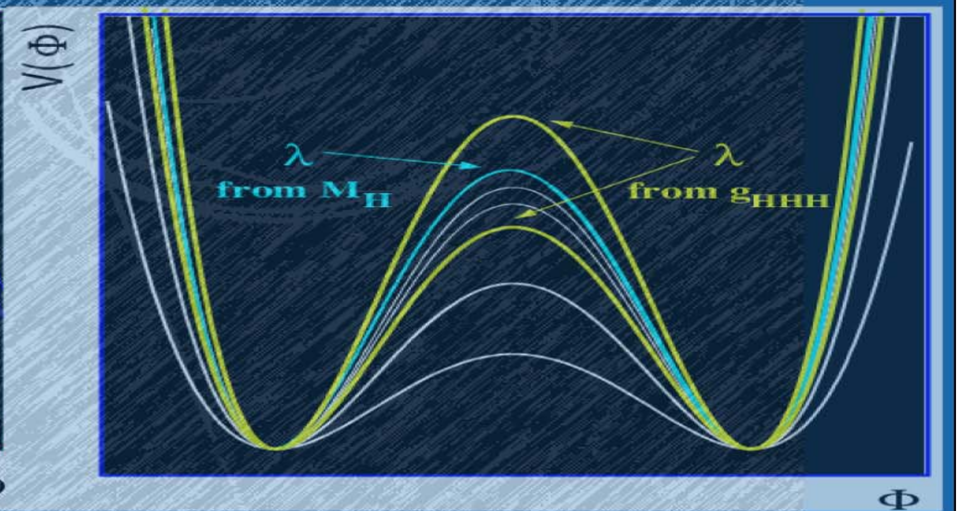
ILC Physics and Origin of Mass

ILC will provide the accuracy in the study of the Higgs profile that will test the Higgs mechanism of EWSB and will explain the Origin of Mass;

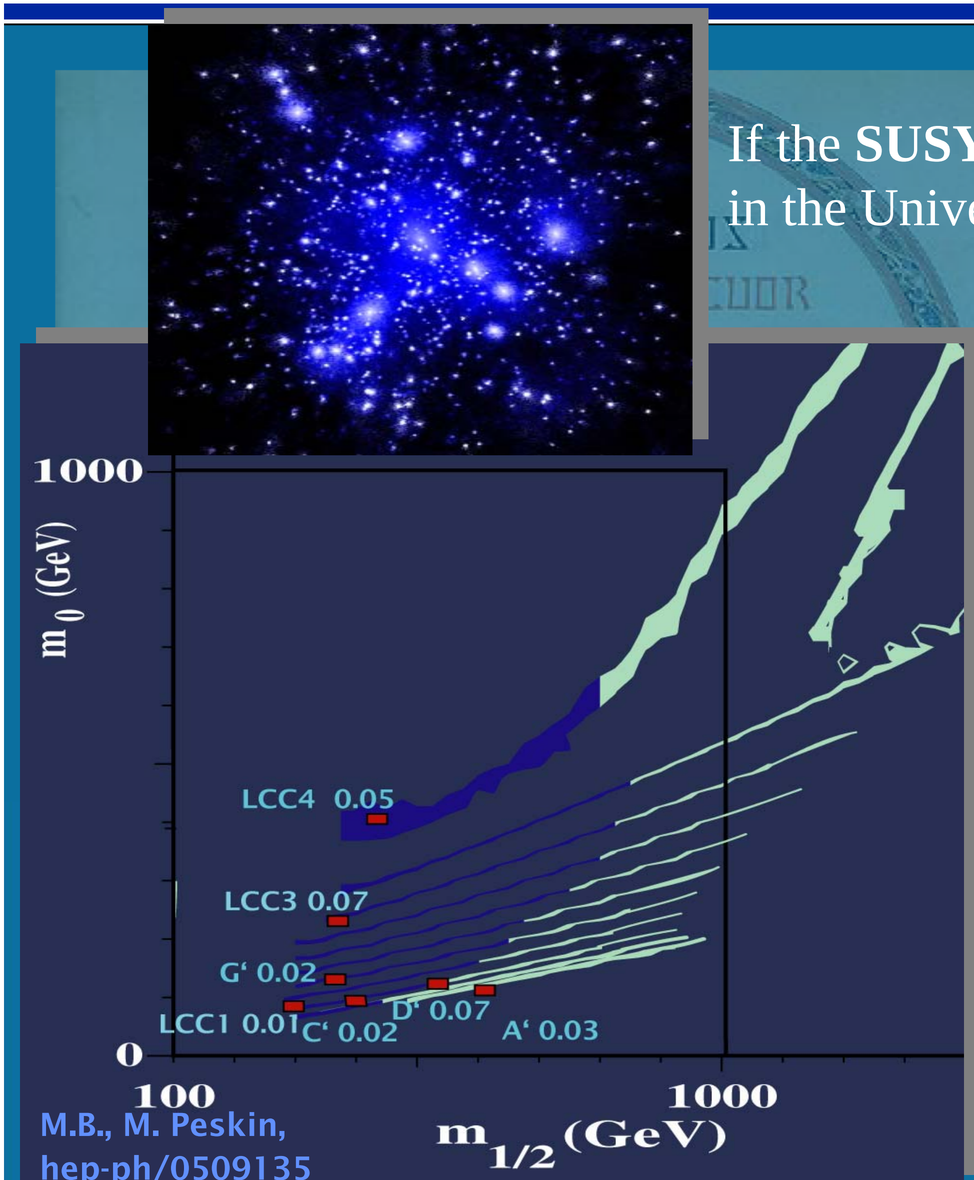
ILC ability to access Higgs self-coupling will provide direct probe on the structure of the Higgs scalar potential, which represent an intriguing template for addressing the questions of the nature of Dark Energy and Inflation;

Anticipated ILC Accuracy supported by significant improvement in **heavy quark mass determinations** at **Babar** and Belle;





ILC Physics and Cosmology



If the **SUSY neutralino** is responsible for Dark Matter in the Universe expect significant signals at the LHC;

But to fully understand the role of the newly discovered particles in determining the Dark Matter and its impact on the history of the Universe, the **accuracy provided by the ILC** in studying its microscopic properties and those of the other relevant particles is **crucial**;

A sample of scenarios, widely different in terms of phenomenology and requirements shows that the **ILC has the capabilities to promote the study of SUSY Dark Matter** to an **accuracy competitive** to that of **present and future satellite CMB data**.

ILC Physics and Detector Benchmarks

ILC World-wide steering committee set up Benchmark Panel to aid process of detector optimisation by proposing a minimum set of physics modes that cover capabilities of detector performance;

Defined set of benchmark processes whose target performances are motivated by quantitatively well-defined requirements.

Physics Benchmarks for the ILC Detectors

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Y. Okada
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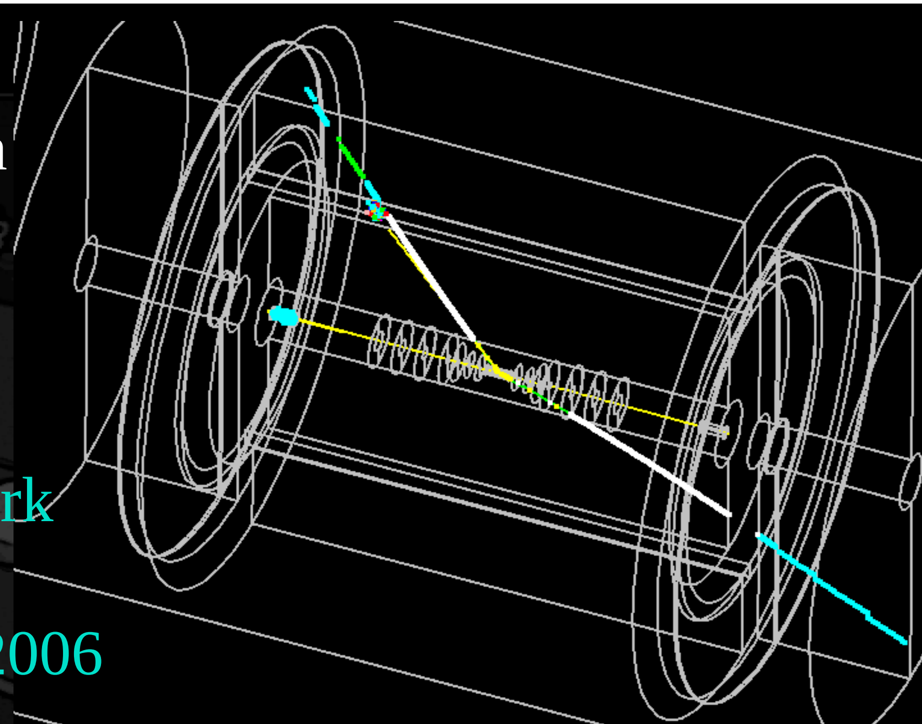
S. Yamashita
International Center for Elementary Particle Physics, University of Tokyo, Tokyo 113-0033 JAPAN
P. Zerwas
DESY, Hamburg D-22603 GERMANY

This note presents a list of physics processes for benchmarking the performance of proposed ILC detectors. This list gives broad coverage of the required physics capabilities of the ILC experiments and suggests target accuracies to be achieved. A reduced list of reactions, which capture within a very economical set the main challenges put by the ILC physics program, is suggested for the early stage of benchmarking of the detector concepts.

LDC and GLD Design Studies

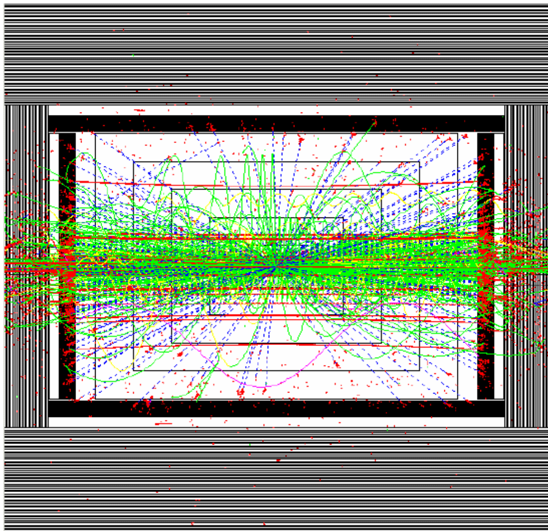
Large Detector Concepts:
ILC detector designs based on
3D TPC Main Tracker and
highly segmented ECAL



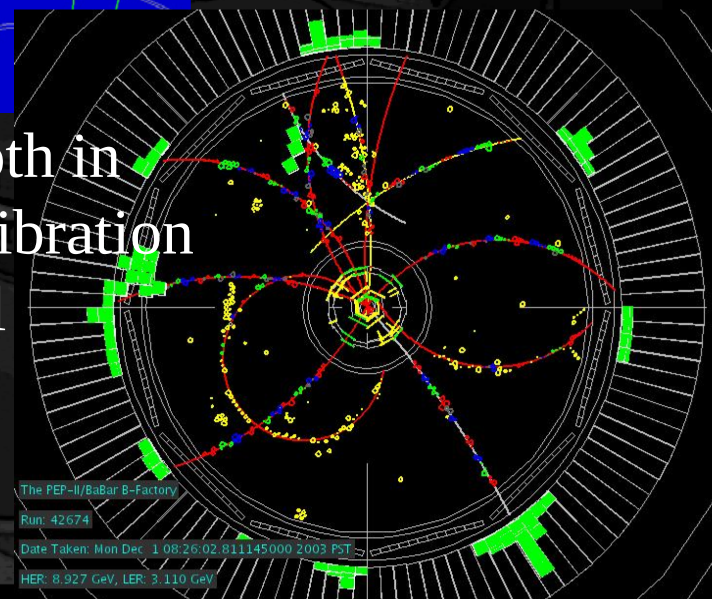
Detector Design Study to
optimise and physics benchmark
integrated detector concepts:
provide first costed design in 2006

Design activity to bridge between
physics studies to **R&D** assessment
LBNL providing leadership in International LDC and GLD Studies
involving DESY, IN2P3, INFN, Ecole Polytechnique, Cornell, Purdue, Victoria, KEK, ...

ILC Detector
Simulation and Reconstruction



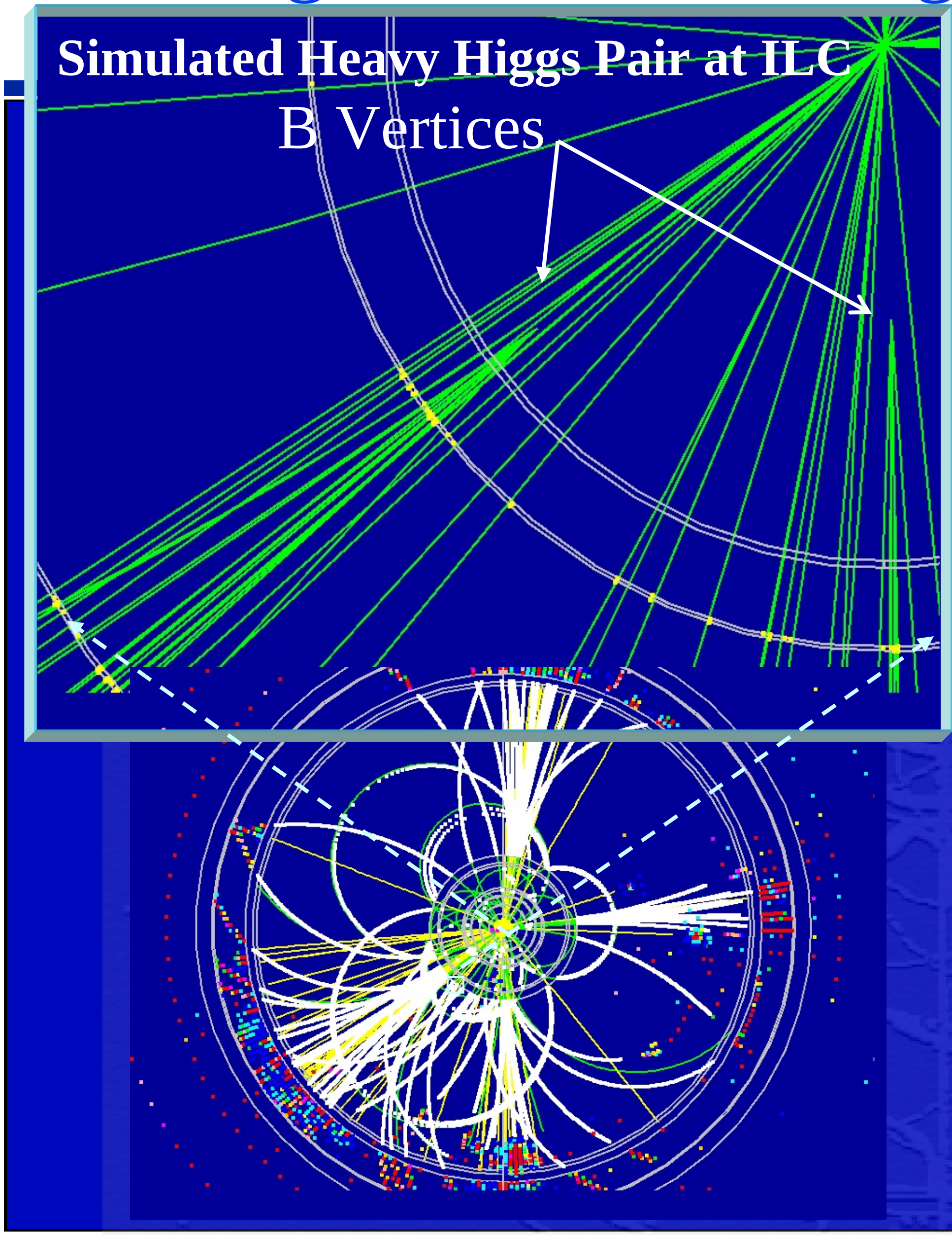
Detector Design and R&D supported by detailed simulation and reconstruction studies including machine induced backgrounds;



Experience with Babar and ATLAS both in software design and reconstruction/calibration algorithms forms basis for a successful contribution to ILC software

NERSC support for computing-intensive simulation and data repository

Tracking Performance Targets



Extrapolation to Collision Point

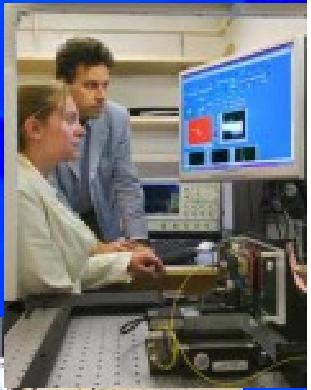
$\sigma_{ip} = a \oplus b / p_t$	a (μm)	b (μm GeV)
LEP	25	70
SLD	8	33
LHC	12	70
RHIC II	14	12
ILC	5	8

Momentum

$\delta p / p^2 GeV^{-1}$	TPC Only	All Tracker
LEP	$1.2\ 10^{-3}$	$5\ 10^{-4}$
LHC	--	$2\ 10^{-4}$
ILC	$1.5\ 10^{-4}$	$6\ 10^{-5}$

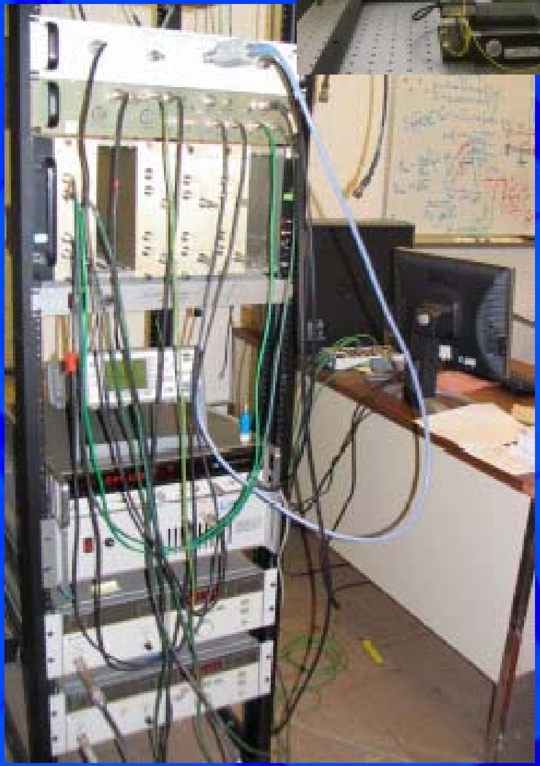
ILC Lab for Advanced Detector R&D

New Detector R&D Lab for ILC Activities to host:



Monolithic Si Pixel Detector
Testing Facility (**LDRD**)

TPC VLSI Readout Test Chamber
and ATLAS Pixel Chip DAQ system



Nano BPM Test Setup for
RF Electronics and DAQ (**LCRD**)

ILC Detector R&D Program at LBNL

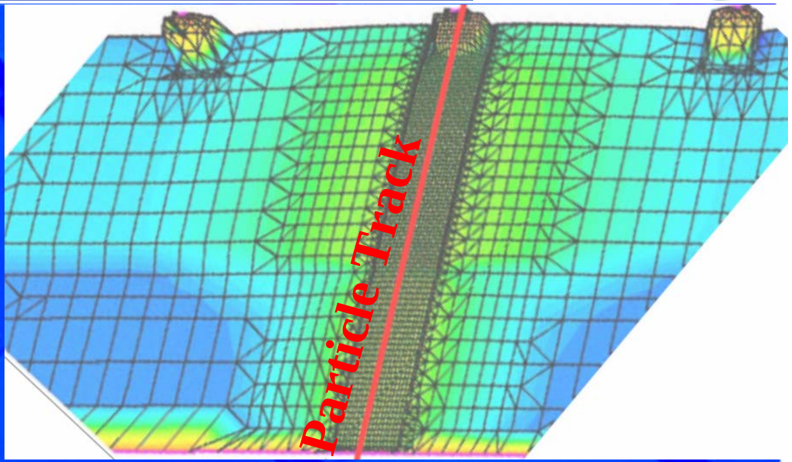
ILC R&D (Si Pixel LDRD and TPC VLSI) based on synergy with Lab efforts aimed at different applications: share common technological basis and bridge from for state-of-art detectors for LHC and RHIC to future ILC Collaborations

- Hybrid Pixel Sensors and VLSI for **ATLAS** (K. Einsweiler, Physics)
- Nanoscale VLSI for **SLHC** (K. Einsweiler, M. Garcia-Sciveres, Physics)
- CMOS Pixel R&D for **STAR** Vertex Upgrade (H. Wieman, Nuclear Science)
- CMOS Pixel R&D for **Electron Microscopy** (P. Denes, Engineering)
- CPCCD for experiments at **Synchrotron Light sources** (P. Denes, Engineering)
- Thick CCD sensors for **SNAP/JDEM** (SNAP Group, Physics)
- TPC for **STAR** Experiment at RHIC (Star Group, Nuclear Science)

ILC Program addresses key R&D issues exploiting opportunities at the interface between different fields and applications. It offers valuable opportunities to train young physicists in instrumentation and design of experiments.

Novel Monolithic CMOS Pixel Sensors

from Digital Cameras to Accelerator Experiments:

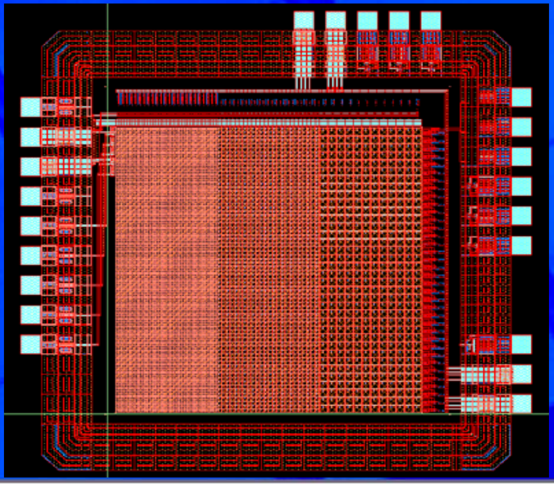


Combine signal process on detector chip:
pioneering experience at IReS,
LBNL has provided proof of concept:

Fabrication process: industry standard, cost effective, easily available

CMOS sensors offer **excellent single point resolution** O(1 μm), good radiation tolerance and **minimal thickness** O(50 μm)

Now need to develop into smart sensors with fast read-out capability and data reduction implemented on chip:



Important interplay with applications beyond boundaries of particle physics (medical imaging, electron microscopy, astronomy, ...)

LBNL CMOS Pixel Sensor R&D

Monolithic CMOS Pixel Sensors in LDRD Program

First submission: AMS 0.35µm CMOS-OPTO process through MOSIS

14µm epi layer, low dark current

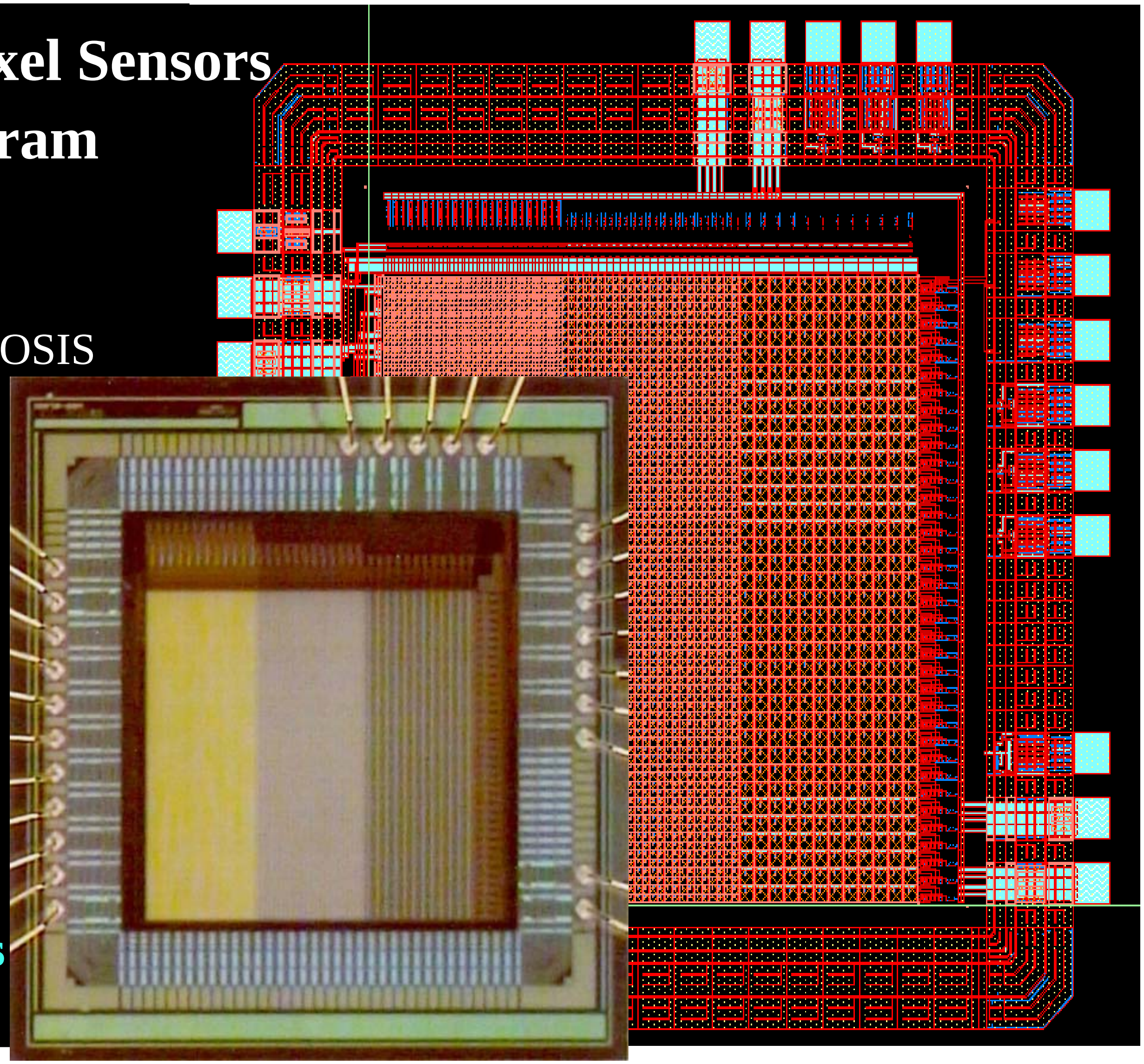
Three Pixel Geometries

12 x 36   40 μm^2 pixels,

24 x 72   20 μm^2 pixels

48 x144 10 μm^2 pixels

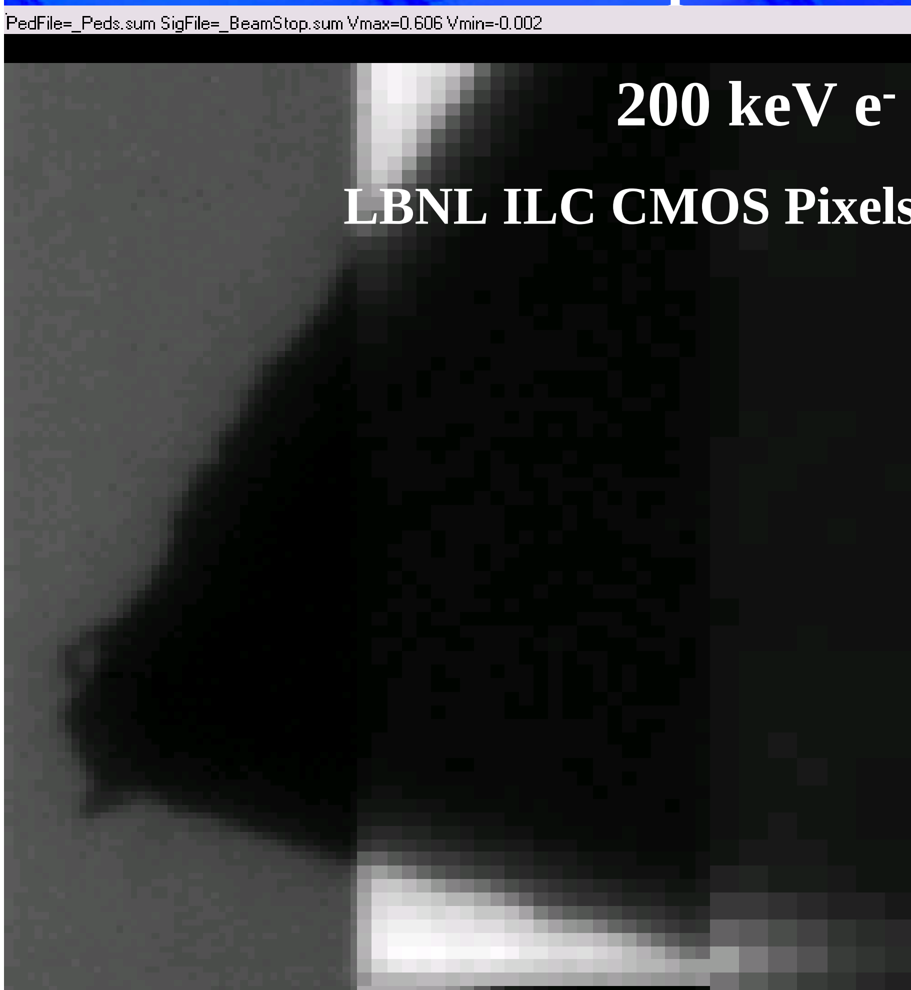
Collaborative effort with NS and Engineering Divisions



LBNL CMOS Pixel Sensor R&D

Detectors tested at the JEOL 200CX TEM electron microscope at LBNL NCEM

200 keV e^- Beam Stop Image

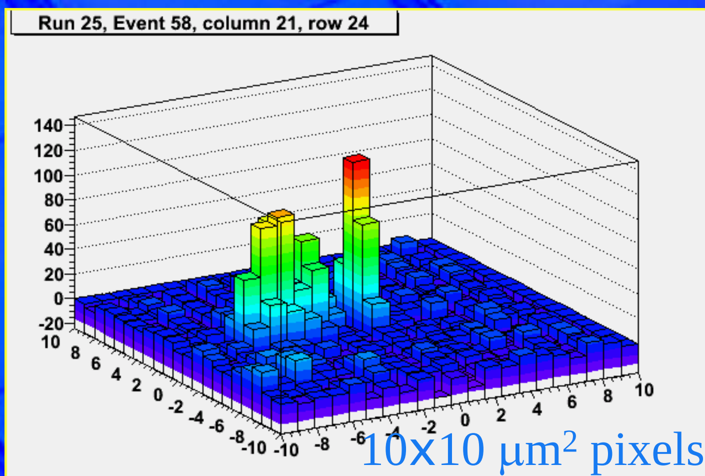


LBNL ILC CMOS Pixels

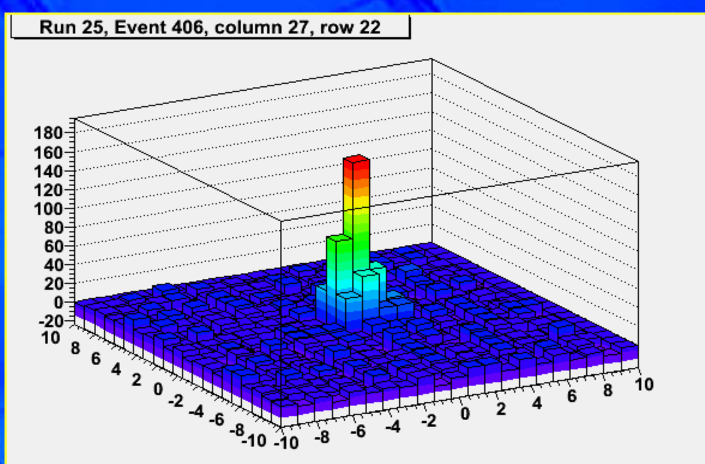
Photographic Film

LBNL CMOS Pixel Sensor R&D

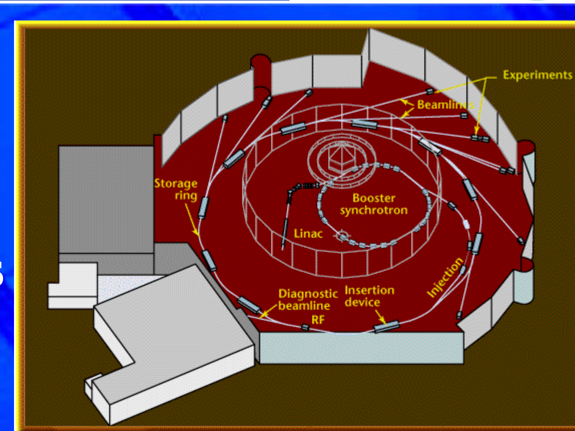
Beam test at LBNL ALS BTS
1.5 GeV e^- beam



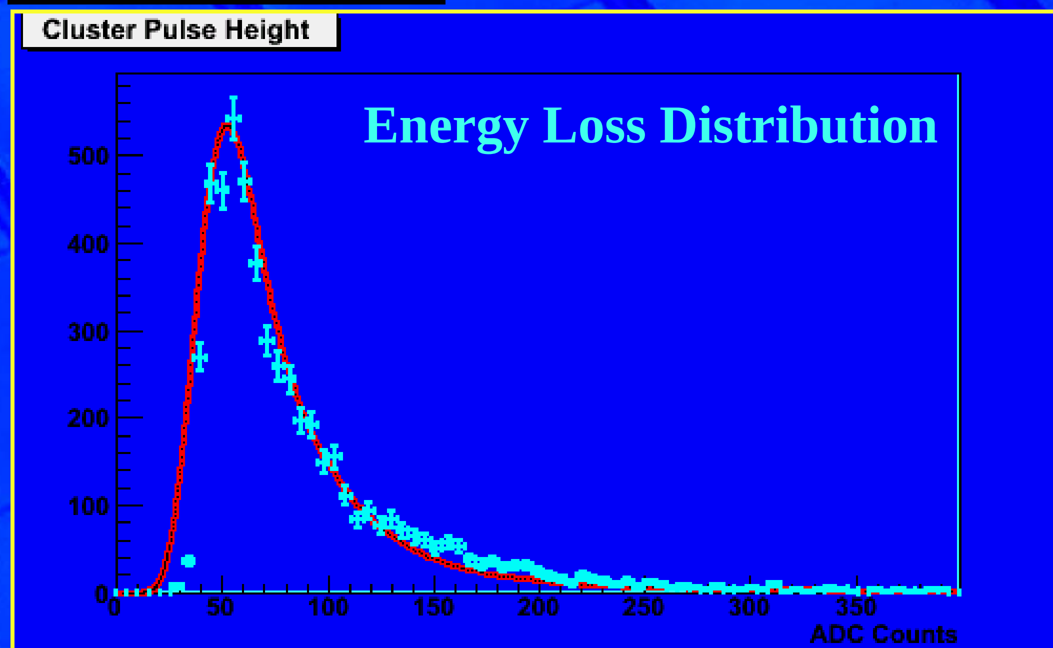
10x10 μm² pixels



First beam on Nov 4
Very Preliminary Results



S/N	<# Pixels>
12	3.5

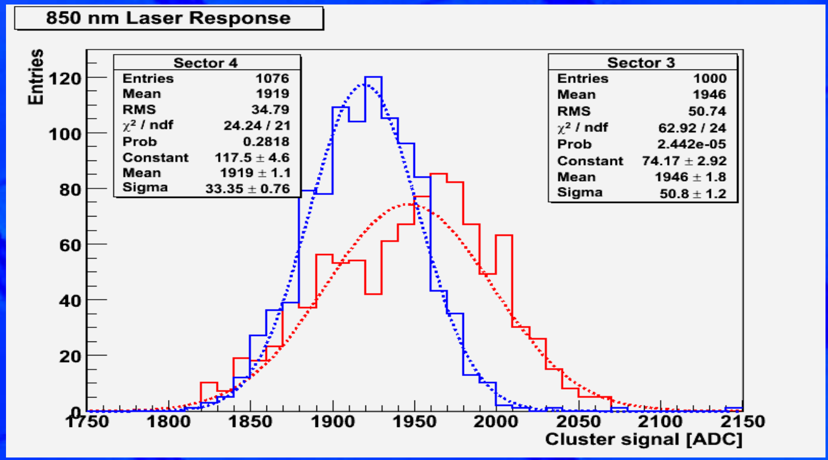


LBNL CMOS Pixel Sensor R&D

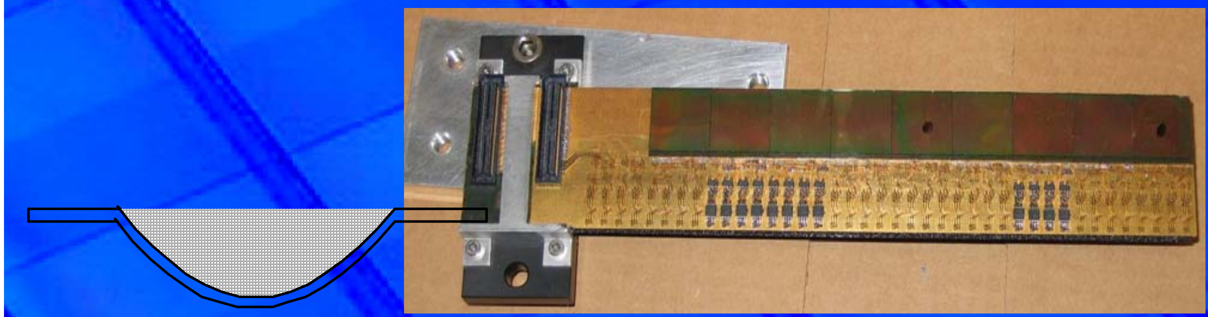
Sensor Backthinning and Engineered Module Design

Perform post-process backthinning of diced MIMOSA V chips down to epitaxial layer: R&D with Bay Area industrial partner;

Systematic program of chip characterisation with laser at different wavelengths and ALS e- beam to study effects of bulk charge collection and changes in backside reflection;



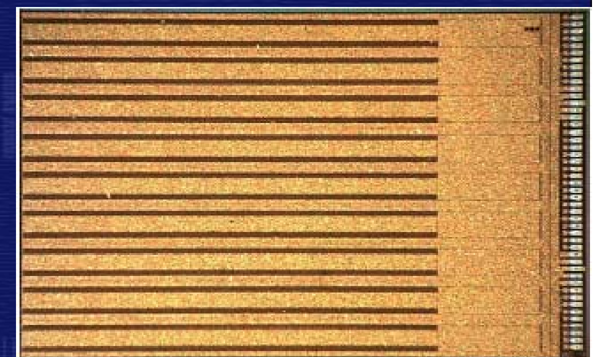
Share experience with STAR VTX group on module design and with Babar on module distortions and alignment.



Thinned Si 50μm	0.05% X_0
RVC Fill + CFC 100μm shell	0.08% X_0
Total	0.13% X_0

LBNL TPC with VLSI Readout R&D

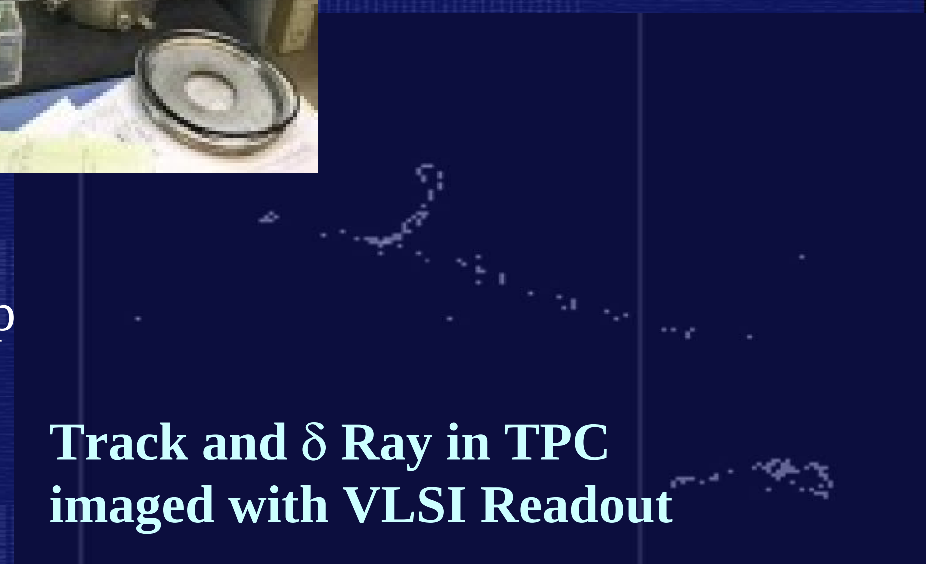
Large volume Time Projection Chamber offers desirable continuous 3D track reconstruction and dE/dx; need to match readout technology to needed granularity for optimal 3D resolution, exploit ion beam GEM fabrication technique at LBNL.



New concept of TPC readout by VLSI chip offers ultimate resolution and potentially very thin endplates:

LBNL Digital TPC R&D

Build small scale **TPC prototype**,
First demonstration of 3D VLSI imaging and evaluate TPC **VLSI readout** using LBNL-designed **ATLAS Pixel chip;**
start conceptual **system design** of custom chip addressing: time resolution, dynamic range, input protection, system noise reduction

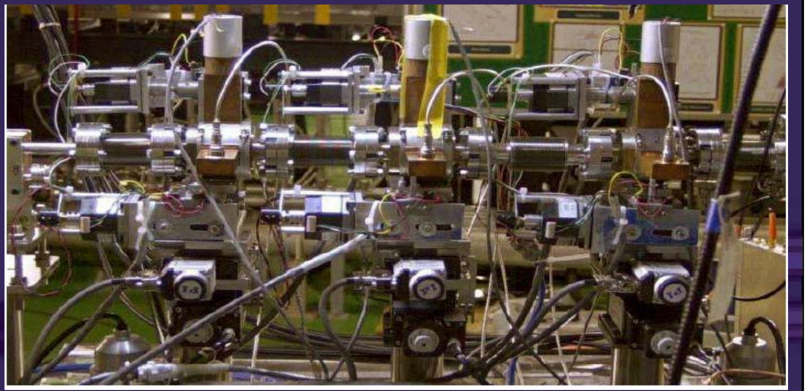


Track and δ Ray in TPC imaged with VLSI Readout

NanoBPM and Energy Spectrometer

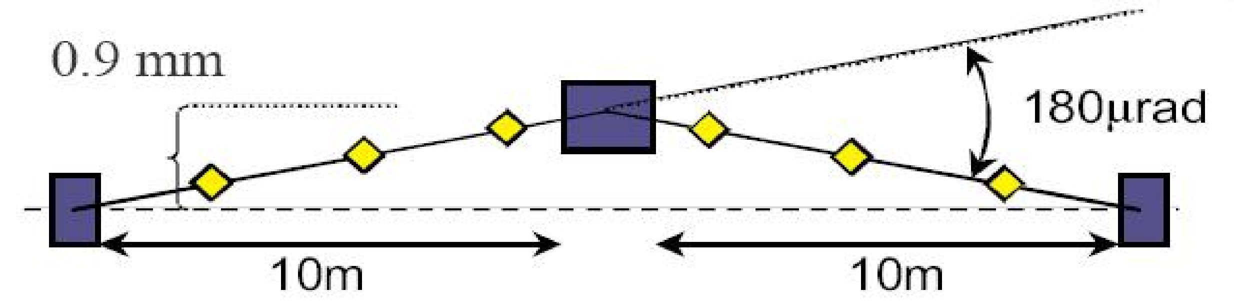
ILC needs single pulse beam position monitor to O(10 nm) accuracy:
- position resolution and accuracy for **IP beam feedback**;
- beam tilt measurement for **luminosity preservation**.

Collaborative effort with SLAC, KEK, LLNL and UC London; supported by UCB LCRD grant

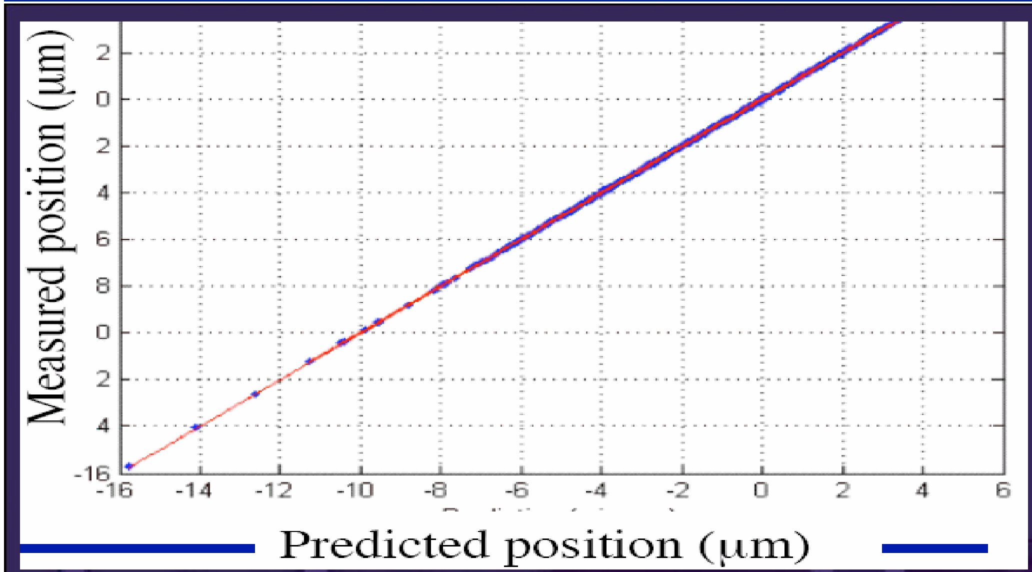


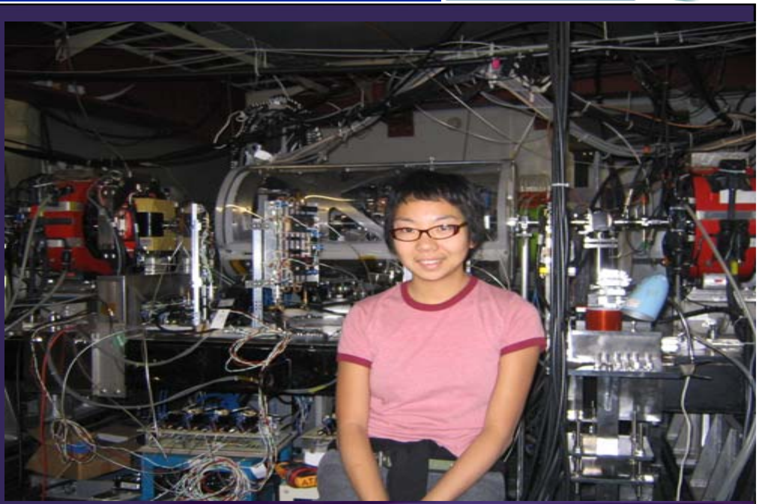
ILC Physics program requires **beam energy** to be known to better than 10^{-4} (factor 3 better than achieved at LEP): design of spectrometer based on BPMs upstream of IP →technology demonstrator before ILC TDR:

Beam Energy Spectrometer Collaboration (UCB, SLAC, Notre Dame, UC London)

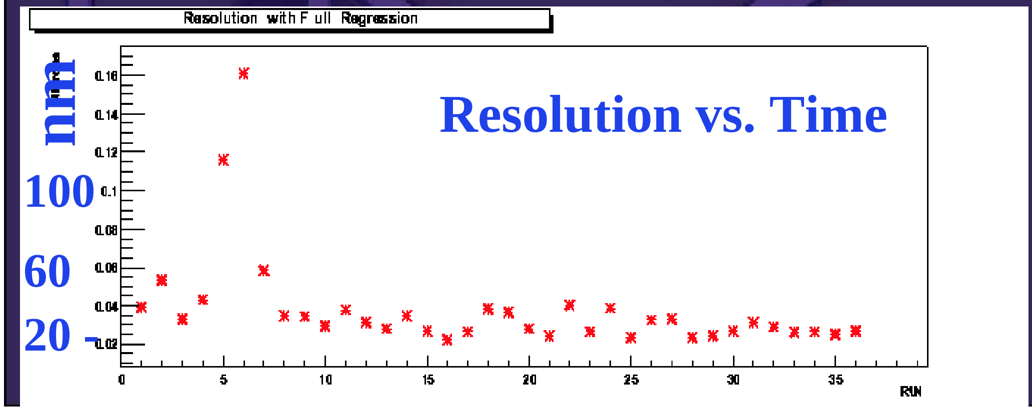


NanoBPM Beam Test at KEK ATF





DAQ, Data Analysis, Laser Anchor System:
Preliminary results show ~20 nm accuracy



Near-term Goals

- Develop next-generation Monolithic Pixel sensors with on-pixel CDS and on-chip data sparsification;
- Demonstrate 3D Imaging in TPC with VLSI readout;
- Launch Reconstruction Software effort matching R&D needs, based on current Babar (ATLAS) experience;
- Start effort on mechanical design of Si Pixel ladder;
- NanoBPM Test Beam at SLAC End Station A
- Develop LDC & GLD detector studies within International collaborations;
- Initiate collaboration with other national Labs on detector R&D and engage University groups in collaborative R&D programs sharing Lab infrastructures.

Long-term Plans

- Develop 1M pixel sensor with full data reduction
- capability, small thickness, low power consumption and fast readout speed to be tested on high en. beam;
- Establish leadership in detector studies and advanced tracker R&D and develop network of Lab and University groups collaborating on R&D and Physics Analyses;
- Develop synergy with LBNL Babar and ATLAS efforts in software and detector developments and study of physics opportunities;
- Need long-term funding profile and adequate staff to support planned activities and set our role in the US and International community.